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Original Article

OPTIMUM BRACING POINT(S) FOR LONG COLUMNS UNDER UNIAXIALLY LOADING CONDITIONS USING PATTERN SEARCH

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ABSTRACT

Pattern search PS method is an effective method for finding the optimum results of any kind of optimization problem, The big advantage of using any method in engineering optimization problems specifically, is that it can be used with highly constrained design of structures. Finding the optimum bracing point for long columns design represents a challenging problem to the efficiency of any optimization method. By limiting the design procedure with many non linear constraints for the buckling stability of long columns according to the ACI code 2011 limitations. Although, PS was used before in concrete design problems, the effect of buckling was not introduced in designing an optimum section of reinforced concrete long columns especially in finding the optimum bracing point(s). A new approach was used here for this kinds of problems, which was introducing a highly constraint function as an objective function. Although, it will be more efficient to use more than one objective function (multi optimization), the limitation of the solver prevent that.

A predictable long column design example was first solved with these non linear constraints to check the efficiency of PS method in finding an optimum bracing point. After that, other examples were solved for other loading conditions. Also, these examples were solved again using Genetic Algorithms GAs to check the solution. It was found that, by using more than one bracing point in finding an optimum section that resist the applied loads and moments using PS, a slight difference will accrue than using only one bracing point. Approving for the fact that, even when the designed problem is highly constrained as finding an optimum bracing point of reinforced concrete long column under buckling effect, the PS still gives an excellent results for design.

KEYWORDS: Optimum Bracing Point, Pattern Search, Structural Optimization, Reinforced Concrete Structures, Buckling Effect

ABBREVIATIONS

PS	Pattern Search
MADS	Mesh adaptive search
f_c'	Concrete compressive strength
$f_{s,com}'$	Yield stress of the compression steel
$f_{s,ten}$	Yield stress of the tension steel
y^-	Plastic centroid of the un symmetrical section
ρ_{com}	Reinforcement ratio at the compression face of the cross section
ρ_{ten}	Reinforcement ratio at the tension face of the cross section
δ_{ns}	Moment magnification factor
ψ	Stiffness ratio of the compression members to the tension members at a joint.

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INTRODUCTION

The method used here (Pattern Search PS), uses an algorithm that allows it to search a specified set of point called a mesh, that represents potential solutions to the problem around the current point. Therefore a start point for each design variable used in the problem should be specified prior to the solution.

PS method contain three algorithms for computing the candidate points for an optimum solution:

- GPS (Generalized Pattern Search).
- GSS (Generating Set Search).
- MADS (Mesh Adaptive Search), this algorithm will be used here.

Each of these algorithms differs from the others by its pattern formed by a scalar multiple of a set of vectors that will be added to the current point.

These patterns specifies which point will be searched at each iteration, using Matlab (The MathWorks Inc 2010). A complete search was adopted here, that specify whether all the point in the mesh should be searched in each iteration. Depending on the used poll method, the algorithm used here select a random collection of vectors to form the pattern, either 2N or N+1 pattern will be used, these patterns can be represented by:

The First Positive Basis (2N) Consists of the Following Vectors

V1=[1 0 0], V2=[0 1 0], V3=[0 0 1],

V4=[-1 0 0], V5=[0 -1 0], V6=[0 0 -1]

While the second positive basis (N+1) consists of the following vectors:

V1=[1 0 0], V2=[0 1 0], V3=[0 0 1],

V4=[-1 -1 -1]

These pattern will be multiplied by the mesh size and then it will be added to the current point to form the new mesh that will be searched. Also, the mesh size is changed according to the poll whether it was successful or not.

To eliminate redundant computations, the “cache” option was used here in order to store a history of the already visited points using pattern search.

The second method used here to check the solution is GAs, it is a robust method for optimization problems, and preferred to be used than other optimization methods with constraints problems, and the engineering field is full of this kind of problems.

This method depends on the natural selection of the best individuals through three main operations (Selection, Cross over and Mutation), First of all, a whole generation of individuals is created, these individuals stands for a potential solutions to a specified problem, then a selection procedure took place to select the most fitted solution to be passed through the next step of solution which is the cross over. The cross over step represents an exchanging process between each two potential solution (chromosomes), this exchange process yield a new and an enhanced two chromosomes as compared to the first ones, this privilege for the new solutions is gained by comparing them with the previous solutions

through a fitness or objective function specified by the designer and according to the problem requirements.

The last main step of the solution is the mutation procedure, which is done by flipping the value of one gene from a chromosome from zero to one or one to zero (randomly chosen) if the binary encoded system was used, in order to ensure the diversity of the solutions to the specified problem and that the GAs solver does not trapped in a local optima.

An additional step may be introduced to the solution, such as (Elitism) which mean that the best individual according to their fitness will be transmitted to the next generation without entering the basic steps of the solution. Also, a hybrid function was used here which narrow the field of the potential solution and the most fitted ones, and make the solver starts the solution from a better individuals than the previous generation. Those two steps were used in this study.

An optimum weight design of plane steel frame was found by (Kameshki, E. S. and Saka, M.P. 2001) using GAs, the design constraints were specified (including serviceability limit state) according to BS 5950 - 1990 -, the optimum weight among the used systems was found to be the x-bracing system with pinned beam-column connections.

Optimizing the base column that affect the base plate size of a steel frame was conducted by (Yeates, Christopher H. 2010) using GAs, the brace area was minimized by about 25 % especially on the ground levels.

A braced frame shape was topology optimized by (Stromberg, Lauren L., et. al. 2012), by modeling beams and columns using two nodes beam element, and the space between each two columns and two beams was modeled using quadrilateral elements. Verifying for an optimum frame the constant state of stress.

Finding structural configurations with minimum cost of steel frames was carried out by (Balogh, T. and Vigh, L. G. 2013) using GAs under seismic loads, the used design constraints were taken from the Eurocode 3 and Eurocode 8, concluding that the cost of bracing and foundation have a large portion from the total optimum cost of the frames.

Also, the optimum cost design of reinforced concrete frames using GAs was found by (Najem, Rabi' M. and Yousif, Salim T. , 2015). The chosen design constraints were specifically used for slabs, beams, columns (axially, uniaxially and biaxially loaded) (Najem, Rabi' M. and Yousif, Salim T., 2015) from the ACI code 2011, taking into consideration flexural, shear and torsional loading conditions. A pre-generated database was created to chose the sub-optimum section for different structural members.

SOLUTION METHODOLOGY

To start the solution, a few assumptions should be specified, the designed long column is assumed to be braced against side sway, it will be designed with a rectangular cross section and it will be uniaxially loaded with two moments at the two ends of the columns in addition to an axial force.

In order to get the optimum design using GAs, a defined objective function should be provided to the solver, in addition to limiting the design procedure by what called the design constraints, which represents the allowed limits for the design variables specified by the designer that will give a practical and reliable answer. Getting more accurate optimum results will be by involving many design constraints.

The objective function for this case of study is finding the minimum moment and minimum force of the designed section that can resist the applied moment and force to the member. i.e. minimizing the difference between the resistance moment and force with the applied moment and force.

Since the genetic algorithms solver could not handle a multi objective optimization problems with non linear design constraints. Also, most of the structural design problems are non linear, and for this case two objective functions are needed to get the optimum results. So, a single objective function will be provided to the solver which in this case will be:

$$\left[N_{c1} + N_{c2} + N_t\right] - \delta_{ns} M_{applied} \tag{1}$$

Where

$$N_{c1} = 0.85 \times f_c' \times a \times b \times \left(y^- - \frac{a}{2} \right)$$

$N_{c2} = f_{s,com}' \times \rho_{com} \times b \times h \times \left(y^- - d^- \right)$ $N_t = f_{s,ten} \times \rho_{ten} \times b \times h \times \left(\left(h - d^- \right) - y^- \right)$ y^- represents the plastic centroid of the section and it is equals to

$$y^- = \frac{a_1 \times (h/2) + a_2 \times (d^-) + a_3 \times \left(h - d^- \right)}{a_1 + a_2 + a_3} \tag{2}$$

Where:

$$a_1 = 0.85 \times f_c' \times b \times h$$

$$a_2 = \rho_{com} \times b \times h \times f_{s,com}'$$

$$a_3 = \rho_{ten} \times b \times h \times f_{s,ten}$$

And the other objective function will be used as a design constraint in order to limit the applied force with the resistance force.

The design variables of the problem will be the optimum bracing point along the column height that will divide the effective length into two parts, so, two design variables will be used for this case. In addition to that, the optimum section required an optimum design variables also, meaning, the cross sectional dimensions of the column will be used and the reinforcement ratio which will be divided into: tension reinforcement ratio and compression reinforcement ratio. After all, six design variables will be used to find the optimum bracing point of long column.

Alpha-L: The upper length from the bracing point to the end of the column.

Beta-L: The lower length from the bracing point to the other end of the column.

B: Width of the optimum section.

H: Height of the optimum section.

ρ_{ten} **:** Reinforcement ratio for the tension face of the cross section.

ρ_{comp} **:** Reinforcement ratio for the compression face of the cross section.

Another case of study was conducted here, which is finding the locations of two optimum bracing points along the

column height, this will divide the effective length of the column into three parts, giving seven design variables including the cross sectional ones. So, instead of using (Alpha-L and Gamma-L) to represents the total height of the column, the following three part will be used:

Alpha-L: The upper distance from the first bracing point to the end of the column.

Beta-L: The inner distance between the two bracing points.

Gamma-L: The lower distance from the second bracing point to the other end of the column.

Long Column Design Constraints

Since the study case is designing a long column optimally using GAs, a moment magnification factor δ_{ns} was used to amplify the applied moment before designing the column, and the value of this magnification factor was limited by these two constraints according to the values specified by the ACI code 2011 (ACI 318 M–11 2011):

$$(1-\frac{\delta_{ns}}{1}) \leq 0.0 \tag{3}$$

$$(\frac{\delta_{ns}}{1.4}-1) \leq 0.0 \tag{4}$$

Meaning that, the value of δ_{ns} should be greater than or equal to 1.0 and less than 1.4, and the value of this magnification factor can be calculated using the following equations:

$$\delta_{ns} = \frac{c_m}{1-\frac{P_u}{0.75P_c}} \tag{5}$$

$$c_m = 0.6+0.4\frac{M_1}{M_2} \tag{6}$$

Where (M_1/M_2) is positive if the column is bent in single curvature, and negative if the column is bent in double curvature (ACI 318 M–11 2011) (Wight, James K. and MacGregor, James G 2009). The factored moment M_2 should not be taken less than a minimum value of the applied moment for accidental eccentricity (Bezev, Svetlana and Pao, John 2009), which was introduced to the solver using the following design constraint:

$$(1-\frac{M_2}{P_u(15+0.03h)}) \leq 0.0 \tag{7}$$

To ensure that the column will be designed as long column, the slenderness ratio specified by the code for braced column against side-sway was limited by the following constraints:

$$(1-\frac{kl/r}{34-12(M_1/M_2)}) \leq 0.0 \tag{8}$$

$$(\frac{kl/r}{40} - 1) \leq 0.0 \tag{9}$$

Where

- **The Effective Length of the Column**

R: Represents the radius of gyration of the column cross section, and it is equals to:

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{bh^3/12}{bh}} = \frac{h}{\sqrt{12}} = 0.2887h \tag{10}$$

k: Effective length factor, and is equals to:

$$k = \frac{3\psi_A\psi_B + 1.4(\psi_A + \psi_B) + 0.64}{3\psi_A\psi_B + 2.0(\psi_A + \psi_B) + 1.28} \tag{11}$$

ψ **:** Ratio of ($\sum EL/l$) of compression members to ($\sum EL/l$) of flexural members in a plane at one end of a compression member, and is equals to:

$$\psi = \frac{\sum 0.7(EI/l)_{columns}}{\sum 0.35(EI/l)_{beam}} \tag{12}$$

at each connection end of the column

Depending on the degree of cracking, the ACI code specify a multiplied factor for the moment of inertia for columns which is equals to 0.7 and for beams 0.35 (Hassoun, M. Nadim and Al – Manaseer, Akthem 2008).

$$EI = \frac{(0.2E_cI_g + E_sI_s)}{1 + \beta_{dns}} \tag{13}$$

or: $EI = \frac{0.4E_cI_g}{1 + \beta_{dns}}$ (14)

β_{dns} **:** The ratio of maximum factored axial sustained load to maximum factored axial load associated with the same load combination, the term (1+ β_{dns}) reflect the effect of creep on the column deflections (Wight, James K. and MacGregor, James G 2009).

$$(\frac{\beta_{dns}}{1} - 1) \leq 0.0 \tag{15}$$

$$P_c = \frac{\pi^2 EL}{(kl)^2} \tag{16}$$

And finally, the constraints of the optimum bracing point was done by limiting the two parts of the column divided by the bracing point with the following equations:

$$(1-\frac{Alpha-L}{0.0001})\leq 0.0 \text{ and}$$

$$(1-\frac{Gamma-L}{0.0001})\leq 0.0 \tag{17}$$

$$(\frac{Alpha-L}{L_u}-1)\leq 0.0 \quad \text{and} \quad (\frac{Gamma-L}{L_u}-1)\leq 0.0 \tag{18}$$

Alpha-L

Represents the distance between the optimum bracing point and the top end of the column, and it should be limited between a maximum value equals to the whole length of the column and a minimum value equals to 0.0, but it was used as 0.0001 in order to avoid division by zero through the solution procedure.

Gamma-L

Represents the distance between the optimum bracing point and the bottom end of the column, limited by the same values of Alpha-L.

Also, an equality constraint was used here, to ensure that the summation of the two parts *Alpha-L* and *Gamma-L* equals to the total height of the column H, using the following equation:

$$(Alpha\text{-}L)-(\mathrm{H}-Gamma\text{-}L)=0.0 \tag{19}$$

For the case of using two bracing points, the long column will be divided into three parts *Alpha-L*, *Beta-L* and *Gamma-L*. Also, an equality constraint was used to ensure the summation of the three parts will be equals to the total height of the column H, using the following equation:

$$(Alpha\text{-}L)-(\mathrm{H}-(Beta\text{-}L+Gamma\text{-}L))=0.0 \tag{20}$$

$$(Beta\text{-}L)-(\mathrm{H}-(Alpha\text{-}L+Gamma\text{-}L))=0.0 \tag{21}$$

$$(Gamma\text{-}L)-(\mathrm{H}-(Alpha\text{-}L+Beta\text{-}L))=0.0 \tag{22}$$

Other Design Constraints

While the cross sectional dimensions were limited with a minimum value equals to 250 mm (specified by the designer) and keeping its maximum value unlimited, no equality constraints were specified as concerning the cross sectional dimensions, i.e., the is no relation between the height and the width of the cross section, and the reinforcement ratio was limited between its minimum value according to the ACI code 2011 (ACI 318 M–11 2011) which is equals to 0.01 and its maximum value 0.08.

The applied force was limited with $P_{balance}$ of the cross section using the following equations:

$$\left[\frac{P_{applied}}{P_1 + P_2 - P_3} - 1\right] \le 0.0 \tag{23}$$

Where

$$P_1 = 0.85 \times f_c' \times a \times b$$

$$P_2 = f_{s,com}' \times \rho_{com} \times b \times h$$

$$P_3 = f_{s,ten} \times \rho_{ten} \times b \times h$$

$$f_{s,com}' = E_s \in_s^- = E_s \frac{0.003(c - d^-)}{c} \le f_y \tag{24}$$

$$f_{s,ten} = E_s \in_s = E_s \frac{0.003(d - c)}{c} \le f_y \tag{25}$$

RESULTS AND DISCUSSIONS

Checking the Efficiency

The first example was solved to check the validity of the GAs in a highly constrained problem. A column with 11.0 m height was designed using GAs, with applied moment equals to 200 kN.m at each end, and a 2000 kN axial force. The material property were f_c^- = 31 MPa and f_y = 414 MPa. The applied moments were chosen to be equally applied to ensure the symmetry of the member and to check the location of the optimum bracing point that is supposed to be predictable. Also, the attached beams at the two ends of the column were chosen to be symmetrically equal around the x and the y axis of the designed column. The geometrical details are shown in figure 1.

After designing the column optimally using PS (MADS) under the applied loads and limiting the whole design procedure and the results with all the constraints explained before, the optimum results of the designed section was found through only 4 iterations with nearly zero constraints violation as shown if figure 2 and 3 then the objective function is hold still at 0.000227319 kN.m which represents the difference between the applied moment and the resistance moment of the section. Table 1 shows the optimum designed results of the members, noticing that, the optimum bracing point is located at the middle of the column height (at 5.5 m), which is obviously due to the symmetry of the applied loads and the geometry of the sections.

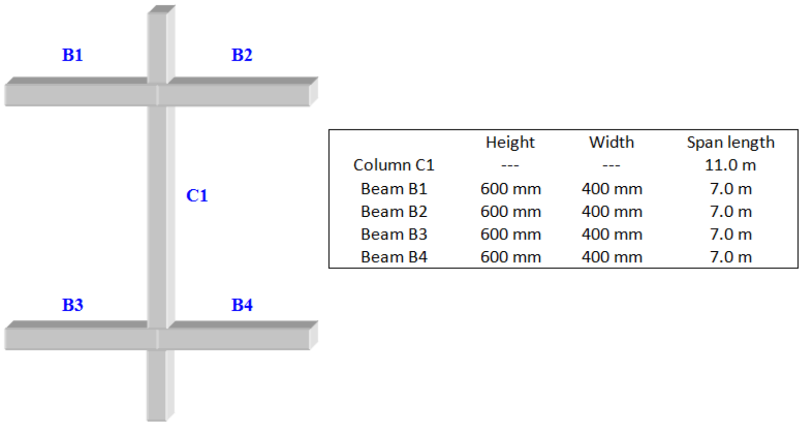

Figure 1: Structural Details of the Designed Column

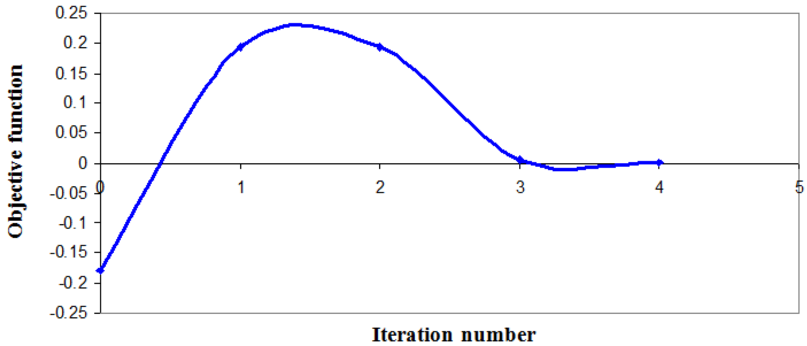

Figure 2: Objective Function through Iterations of the Designed Column using PS (MADS)

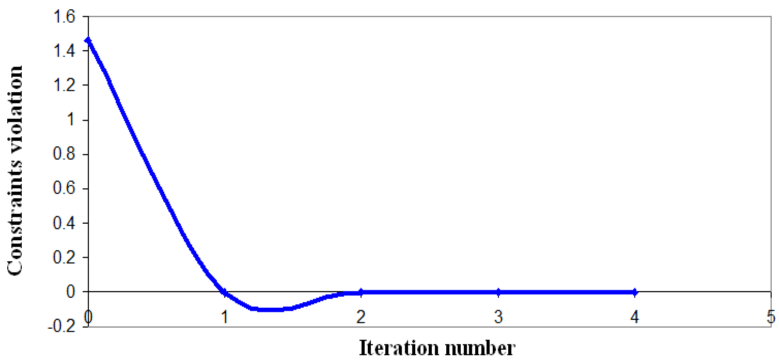

Figure 3: Maximum Constraints Violation through Iterations of the Designed Column Using PS (MADS)

Table 1: Optimum Design Results using PS (MADS) and Gas

	Width (M)	Height (M)	Reinf. Ratio-Ten.	Reinf. Ratio-Comp.	Alpha-L (M)	Gamma-L (M)
PS(MADS)	0.4631	0.3373	0.0030	0.0092	5.486	5.514
GAs	0.4818	0.3419	0.0030	0.0070	5.5	5.5

While by designing the column optimally using GAs under the applied loads and limiting the whole design procedure and the results with the same constraints used before, the method took more iterations to found the optimum results of the designed section with nearly zero constraints violation as shown if figure 4 and 5 then the objective function

is hold still at 0.00862689 kN.m, but finding almost the same optimum section and optimum bracing point that were found using PS (MADS), table 1.

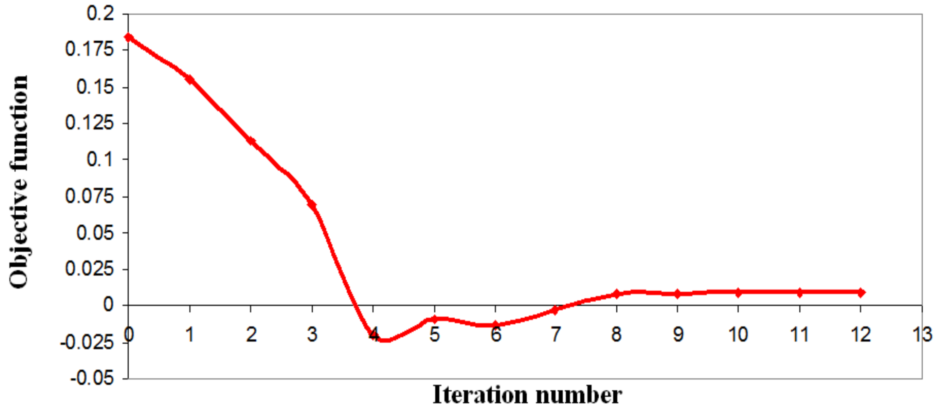

Figure 4: Objective Function Through Iterations of the Designed Column Using Gas

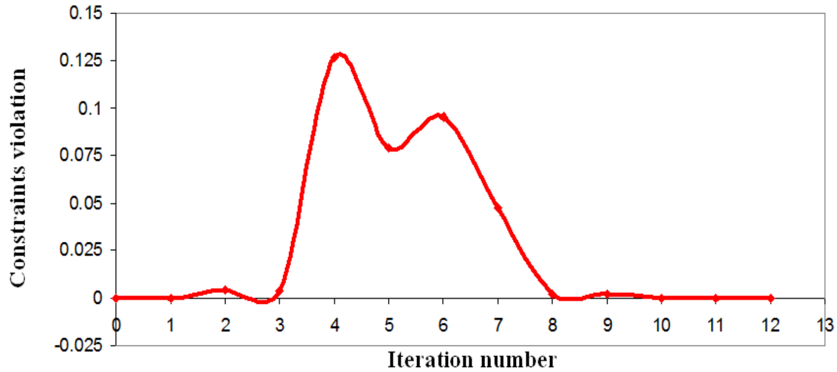

Figure 5: Maximum Constraints Violation through Iterations of the Designed Column Using Gas

Finding the Optimum Bracing Point

The second example was solved to check the difference between the optimum designed section with the optimum bracing point found by PS (MADS) and GAs, and any other optimum section with any bracing point specified previously through the height of the column. A 12.0 m column was designed using GAs by applying a 100 kN.m and 230 kN.m moments at the ends of the column with 2000 kN axial force, f_c^- = 31 MPa and f_y = 414 MPa, the cross sectional dimensions of the upper beams (with the least applied moment) were taken to be as 500 mm height and 300 mm width, with span length equals to 6.0 m each while the geometry of the lower beams were kept unchanged (600 mm height, 400 mm width and 7.0 m span length). By using PS (MADS) and GAs to solve the column optimally and find the optimum location of the bracing point, the results are shown table 2 and figure 6 with objective function equals to 0.000054234, those results were gained through only 4 iterations using PS (MADS) and 6 iterations using GAs with zero constraints violation. The optimum bracing point was located at 6.4994 m (PS(MADS)) from the top of the column. After that, the location of this point was changed repeatedly at each 10% of the total height of the column (one bracing point at a time) and solve it again using the two methods to get a new difference between the applied moment and the resistance moment of the section, the results of these other optimum sections are shown in figure 7.

Table 2: Optimum Design Results using PS (MADS) and Gas

	Width(m)	Height(m)	Reinf. ratio-Ten.	Reinf. ratio-Comp.	Alpha-L (M)	Gamma-L (m)
PS(MADS)	0.2601	0.3805	0.0056	0.0336	6.4994	5.5006
GAs	0.2701	0.3664	0.0087	0.0374	6.5166	5.4834

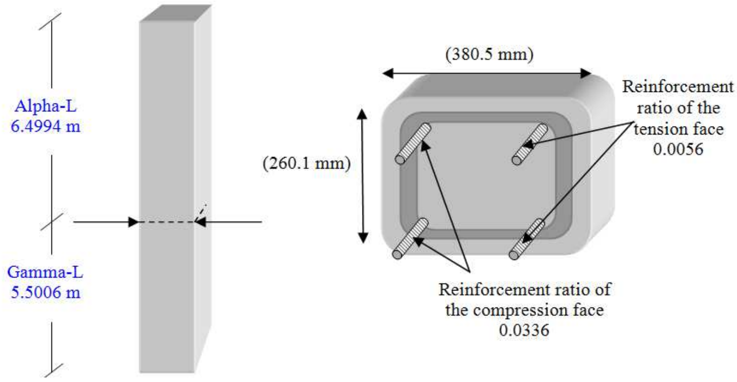

Figure 6: Design Results for the Optimum Bracing Point of Long Column under Uniaxial Loading Condition Using PS (MADS)

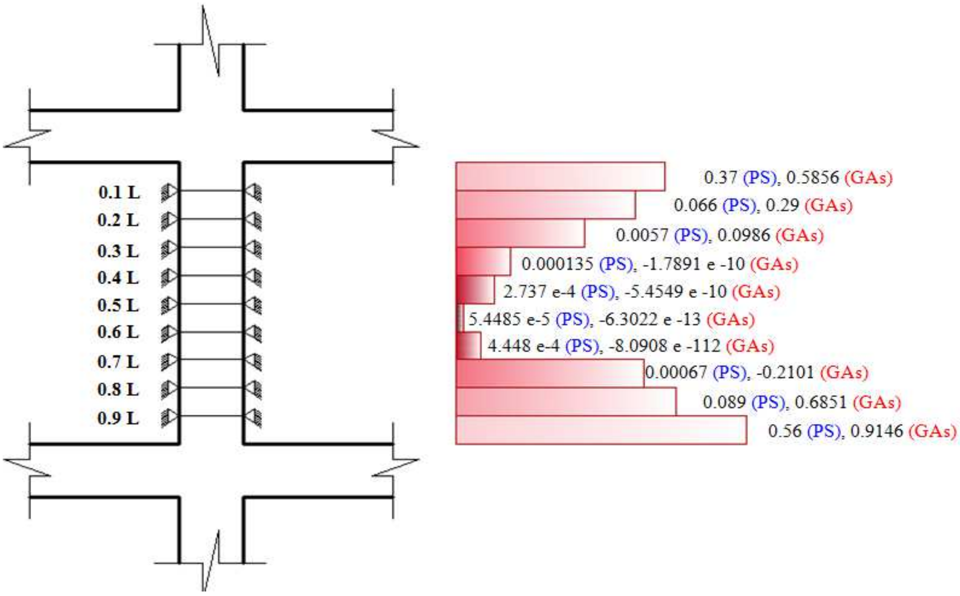

Figure 7: Objective Function at Each Bracing Point through the Column Height

As shown in this figure, by choosing a bracing point located at 0.1 L (1.2 m) of the column height, the difference between the resistance moment and the applied moment is about 0.37 kN.m (using PS(MADS)) and 0.5856 kN.m (using GAs), and for a point located at 0.2 L (2.4 m), this difference is 0.066 (using PS(MADS)) and 0.29 kN.m (using GAs), this difference keep decreasing through the column height as the bracing point keep closing from the optimum bracing point until it reaches to almost zero (5.4485 e-5 PS)(-6.3022 e -13 GAs) at the optimum point and after that it keep increasing as the location of the bracing point moving further from the optimum point toward the other end of the column.

The optimum designed column have different cross sections according to the different locations of the chosen bracing points because of the stochastic nature of the genetic algorithms, this difference is smaller between sections using PS (MADS), but all of these sections gave a higher objective function than the section with the optimum bracing point,

figure 7.

Two Bracing Points

The last example was solved using PS (MADS) and GAs with two bracing points along the height of the columns, the same geometry and applied loads were used from the previous example. The optimum bracing points were found through only four iterations using the two methods, the objective function using PS (MADS) was equals to 2.2317e-005 while it was equals to -9.7614 e-13 using GAs with zero constraints violation. Table 3, figure 8, shows the locations of those points with the optimum designed section. After that, the location of the two bracing points were changed randomly throughout the height of the column in order to check how much difference will it gave between the resistance and the applied moment from the difference gained for the optimum two locations.

Table 3: Optimum Design Results Using PS (MADS) and Gas

	Width (M)	Height (M)	Reinf. Ratio-Ten.	Reinf. Ratio-Comp.	Alpha-L(m)	Beta-L(M)	Gamma-L(M)
PS(MADS)	0.3746	0.3055	0.0050	0.0273	4.4496	3.4872	4.0632
GAs	0.2546	0.5737	0.0112	0.024	4.5809	3.4413	3.9778

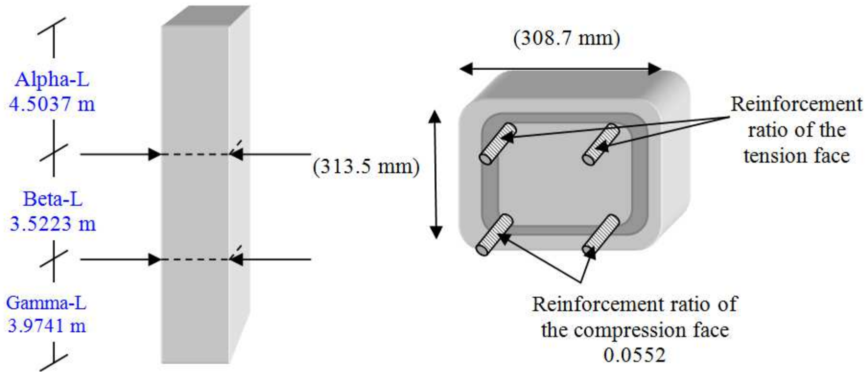

Figure 8: Optimum Design Results with Two Bracing Points for Long Column under Uniaxial Loading Condition Using PS (MADS)

Table 4, shows the optimum designed sections for different locations of the two bracing points, it can be seen that all of these optimum sections having a design moment difference more than the difference of the optimum section that was found earlier with the two optimum bracing points.

Table 4: Optimum Design Results of Columns Randomly Braced in Two Locations

	Width (MM)	Height (MM)	Reinf. Ratio-Ten.	Reinf. Ratio-Comp.	Alpha-L(m)	Beta-L(m)	Gamma-L(m)	Objective Function (kN.m)
PS (MADS)								
Col. - 1	0.4249	0.2934	0.0081	0.0269	2.5417	4.4918	4.9665	0.0021
Col. - 2	0.3249	0.3081	0.0080	0.0388	3.5395	4.4970	3.9635	0.0015
Col. - 3	0.2538	0.5951	0.0030	0.0070	2.1677	2.1482	7.6842	0.2412
Col. - 4	0.3460	0.3128	0.0078	0.0333	1.9706	5.0003	5.0290	9.4226e-004
Col. - 5	0.3407	0.3177	0.0068	0.0323	5.0384	4.9749	1.9866	0.002
Col. - 6	0.2752	0.3456	0.0079	0.0555	3.5292	3.5635	4.9073	0.0582
Col. - 7	0.3714	0.3074	0.0050	0.0275	4.4986	4.5032	2.9982	0.0012
Col. - 8	0.5266	0.3214	0.0032	0.0068	5.9019	4.1045	1.9936	2.1113e-004
Col. - 9	0.2772	0.4176	0.0030	0.0211	2.4946	2.5421	6.9633	0.0401
Col. - 10	0.3139	0.4294	0.0030	0.0135	1.0245	3.4629	7.5126	0.0552
GAs								
Col. - 1	476.1	257.7	0.0235	0.0457	1.9492	5.232	4.8189	-7.9777 e-009
Col. - 2	273.9	375.7	0.005	0.0308	3.1565	6.437	2.4064	-7.4807 e-008

Table 4: Contd.,								
Col. - 3	255.7	396.9	0.0033	0.0292	6.6852	1.5227	3.792	-1.0381 e-012
Col. - 4	417.3	275.2	0.0182	0.0427	3.1854	3.634	5.1806	-8.2686 e-009
Col. - 5	316.9	385.4	0.0035	0.0195	7.0955	1.8959	3.0086	-6.5741 e-008
Col. - 6	299.9	300.9	0.015	0.0532	3.9287	3.4422	4.6291	-1.7166 e-012
Col. - 7	350.3	264.2	0.0601	0.0054	4.9624	4.9408	2.0967	-1.2572 e-010
Col. - 8	275.8	323.7	0.0167	0.0546	5.5347	1.0441	5.4212	-2.2029 e-007
Col. - 9	676.2	253.9	0.0095	0.0153	3.947	3.0442	5.0089	-1.1224 e-007
Col. - 10	270.2	305.6	0.0504	0.003	3.0116	3.6917	5.2968	-8.4347 e-008

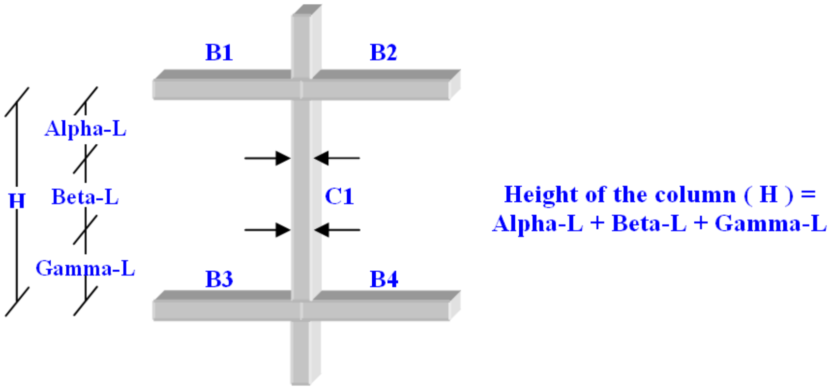

Figure 9

CONCLUSIONS

A highly constraints problem was presented here, with so many non linear design constraints to checkout the ability of PS (MADS) in solving this kind of problems.

Although PS (MADS) took more time in finding the optimum design results, GAs gave a highly accurate results as concerning a highly constrained problem such as long column design specially when using a stability constraints. Even though, using two bracing points gave a better results than one point using the two methods, the use of one bracing point gave a great and accurate optimum results on its own.

In many cases through the solution, it was noticed that PS (MADS) method can be trapped in a local optima. To overcome this, the starting points for the optimum results were changed repeatedly to get the global optimum point. This was not a problem by using GAs, it was rarely gave a local optima as a final results.

Enhancing GAs method, so that it can handle non linear design constraints with the multi objective optimization problem will put this method on the top of the available choices for the designer indisputably.

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